

AN INVESTIGATION OF THE EFFECT OF CERTAIN
FACTORS ON THE STRENGTH AND COMPRESSIBILITY
OF CLAYS

BY

ORESTE MORETTO

C.E., Universidad del Litoral, Argentina, 1940

M.S., University of Illinois, 1944

AN ABSTRACT OF A THESIS
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
ENGINEERING IN THE GRADUATE SCHOOL OF
THE UNIVERSITY OF ILLINOIS, 1946

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INTRODUCTION

In the literature of soil mechanics, much discussion has centered about two questions, namely:

Wherein lies the source of the rigidity of undisturbed clays?

What is the relation between void ratio and pressure for sedimented clays?

Until recently, these questions have appeared to be of academic importance. However, they do have important practical implications, some of which have been emphasized by the results of field observations in the last few years.

This thesis represents an attempt to explore certain phenomena which may have a bearing on these two interrelated questions.

The great decrease in strength experienced by some clays when remolded at unaltered water content was first observed by the Swedish Geotechnical Commission during the investigation of landslides.¹ Subsequently, A. Casagrande² observed that the consolidation characteristics of undisturbed and remolded clays are also markedly different, and he concluded that such disturbing events as the driving of piles into soft clay are likely to increase the compressibility of the clay to such an extent that the piles would actually be detrimental. In order to explain the difference in the physical properties of undisturbed and remolded clays, Casagrande proposed a theory according to which the clay particles settle during the process of sedimentation into a definite arrangement called the "clay structure".

Casagrande states that "the building up of such a structure is chiefly dependent on the exceedingly slow process of natural sedimentation and consolidation". Remolding is presumed to destroy the rigid connecting links between the large soil grains that form the structure and to replace them by the unconsolidated soft clay which originally filled the space between the rigid links. Since the development of the links was dependent on the exceedingly slow process of sedimentation, Casagrande

was led to the conclusion that, "if we destroy the structure which nature has taken many centuries to build up, we cannot restore it".

A fundamentally different explanation of the manner in which undisturbed clays acquire their strength and rigidity has been given by K. Terzaghi.³ According to his theory, the strength and rigidity are acquired not primarily by the slow loading of certain connecting links in the clay structure, but by "slow physico-chemical processes" which are due principally to the surface activity of the mineral grains. As a consequence of the surface activity, each clay particle is surrounded by a shell of adsorbed water, almost solid near the particle, and quite viscous within a somewhat greater distance. In the undisturbed state contacts exist between the solid portions of the adsorbed water. Remolding breaks these contacts between the solid water shells, displaces the grains, and introduces the viscous adsorbed water between them, whereupon the clay becomes plastic.

According to Casagrande's conception, the void space of clays with high void ratio consists largely of water-filled chambers surrounded by domes and arches which are themselves not solid but resemble open lace work. According to Terzaghi's view, the adsorbed layers rather than the mineral grains are in contact, and relatively high void ratios can be conceived without resorting to the complex dome-and-arch structure.

The second question, regarding the process by which a natural deposit reached its present state is of little interest to the foundation engineer. However, it may be of prime importance in connection with hydraulic fills.

Most of the current methods for estimating the extent to which a hydraulic fill will consolidate are based on the assumption that the behavior of the soil in the fill will resemble that of the same material in a laboratory consolidation test on a sample remolded at a wet consistency. Remolded samples are used because, according to Casagrande's conception of the structure of natural deposits, there has been far too little time and the rate of deposition has been far too great for the "clay structure"

to develop. Field observations on two dams with hydraulically placed cores have indicated, however, that the settlement of the cores has been far less than the estimated value. This fact suggests that the current conceptions are in need of revision.

The tests performed in this thesis were intended to test the validity of the two concepts concerning the properties of clays, and in addition to add to knowledge concerning the consolidation of man-made sediments.

TESTS AND RESULTS

Tests were made on five types of clay designated as Detroit I, Detroit II, Laurentian, Boston and Mexico. The name indicates the locality from which the material was obtained. The clays were selected on the belief, based on their external appearance and physical properties, that they represented a wide range of clay materials, both mineralogically and physically. Later was discovered that the four first clays were, mineralogically, essentially the same: they were all clays of the illite type. The Mexico clay was entirely different, it was a clay with a high percentage of halloysite, which made it a very unusual soil.

Three types of tests were made:

(a) *Unconfined compression tests*.—Unconfined compression tests were made on all of the clays to determine the gain in stiffness and strength experienced by the material when remolded specimens are kept at constant water content for various lengths of time before being tested. Specimens were made of the various clays, one of them tested immediately and the rest stored at constant water content. They were tested after periods of rest of 3, 7, 14, 28, 60, 120, and 240 days.

The tests indicate that by keeping the remolded clays at a constant water content and in a state of complete rest, the clays increased their strength to different degrees. Some of them gained so much strength that they recovered most of the strength of the original undisturbed clays. For others the gain was not so important.

(b) *Consolidation tests.*—Consolidation tests were made on remolded material from most of the clays. Their purpose was to determine the effect on the pressure-void ratio curve of maintaining a constant pressure on the sample for four weeks, as compared to the curve for a normal consolidation test in which the load was increased by successively doubling the existing load on the sample.

The tests indicate that by maintaining a constant pressure on a sample of remolded clay, its pressure-void ratio curve is displaced horizontally and the clay acquires some of the characteristics of undisturbed clays.

The same results were obtained on a sample of Boston clay that was consolidated to a given pressure, then relieved of it, and stored at constant water content for six months.

(c) *Slurry tests.*—Slurry tests were made to study the consolidation of thin slurries sedimented in the laboratory after the clay had been dispersed in water. The purpose was to investigate the relation between pressure and void ratio for man-built sediments under various conditions of loading. These conditions consisted in varying the rate of loading from one in which the pressure was increased by successively doubling the existing load on the sample, to another in which the pressure was increased at the rate of 1.8 gm. per sq. cm. per day. Furthermore, tests were made in which slurries were kept for various lengths of time under a pressure of 30 gm. per sq. cm. before loading was again resumed.

The tests indicate that the extent to which a man-built sediment will consolidate cannot be determined from a consolidation test on a remolded sample of the material. The final void ratio of the sediment is likely to be much higher than would be deduced from such a test. Slurry tests appear to represent the behavior of a hydraulic fill much more reliably than do ordinary consolidation tests, but the problem is complicated by the influence of the orientation of the mineral grains of the clay and by the rate of deformation to such an extent that it seems doubtful if accurate predictions will be ever possible on the basis of such tests.

CONCLUSIONS

The tests made in this investigation were designed to bring out whatever phenomena might result from the surface activity of the clay materials. They were intended to add laboratory evidence to clarify controversial points of view in relation to the causes that determine the properties of clays and in addition to add knowledge concerning the consolidation of man-made sediments.

The modifications of the clay properties indicated by these tests can be accounted for only by the effect of the surface activity of the mineral grains. Since these effects were influenced to a certain degree by the manipulations to which the material was subjected before being tested, the results for some of the clays can give only an indication of the importance that thixotropic processes may have in determining the properties of undisturbed clays. Yet, the results of the tests as a whole lead to the following conclusions:

(1) The concept of the clay structure as elaborated by A. Casagrande is neither necessary nor sufficient to account for the difference in properties of undisturbed and remolded clays.

(2) Physico-chemical processes resulting from the surface activity of the mineral grains are chiefly responsible for the differences between undisturbed and remolded clays. The mechanism of the physico-chemical processes is conceived to be slightly different from that postulated by K. Terzaghi, but the essential features of Terzaghi's hypothesis are unaltered. As conceived, the mechanism of the physico-chemical processes is such that the properties of the adsorbed water shell may change by increasing its viscosity whenever conditions are favorable. By this means, a clay may regain a great part of its original stiffness and strength after it has been remolded.

In relation to the consolidation of man-made sediments, the tests lead to the following conclusions:

(3) The extent to which man-built sediments will consolidate cannot be estimated on the basis of consolidation tests on remolded samples. The final void ratio of the sediment is likely to be much higher than would be deduced from such a test.

(4) The tests have furnished enough information to indicate that consolidation of a hydraulic fill may proceed in one of two possible ways as follows:

(a) According to an e -log p curve similar to that deduced from a rapid slurry test in which the pressure is increased by successively doubling the existing load on the sample. The final void ratio of the sediment could be deduced from such a test.

(b) According to the same curve to a point at which the void ratio has decreased sufficiently to develop a certain minimum critical amount of bond resistance between the clay particles. Since at this stage the rate of deformation will have decreased considerably, the effect of the surface activity may become more and more important because of thixotropic hardening of the water shells surrounding each particle. As a consequence, the rate of deformation will decrease still more and the resulting e -log p curve will flatten out. The settlement of the fill will then be much smaller than would be anticipated on the basis of a rapid slurry test. Investigations on two existing hydraulic fill dams indicate that in these two particular cases, consolidation of the fills has proceeded as explained in this paragraph.

(5) Slurry tests appear to represent the behavior of a hydraulic fill much more reliably than do ordinary consolidation tests. However, it is not yet possible to predict the settlement of such a fill even by means of slurry tests. Because of the importance of grain orientation and the rate of deformation, it seems doubtful if accurate predictions will ever be possible. The most promising procedure appears to be to collect empirical data concerning the settlement of actual fills and to attempt to relate the results to those of laboratory slurry tests, particularly of tests in which the slurry is kept under a sustained pressure for a certain length of time. Such tests would probably give a measure of the hardening properties of the sediment.

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